Swashzone Fluid Velocities

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LONG-TERM GOALS

The long-term goal is to develop and verify models for fluid and sediment processes in the swash zone.

OBJECTIVES

The overall objective of these projects is to improve models for fluid velocities in the swash zone. Although runup excursions owing to random waves on a natural beach are predicted well by a model (Rbreak) based on the vertically-averaged nonlinear shallow water equations with quadratic bottom friction (*Kobayashi et al.* 1989, *Raubenheimer et al.* 1995), it is not clear whether the cross-shore velocity u is predicted accurately. Furthermore, despite recent results that suggest alongshore sediment transport occurs primarily in the swash and outer surf zones (*Bodge and Dean* 1987, *Kamphuis* 1991, *Thornton and Abdelrahman* 1991), few studies have examined the importance of alongshore swashzone currents. The specific objectives of these projects are to:

- measure cross-shore fluid velocities in the swash zone.
- observe alongshore swashzone fluid velocities at Torrey Pines Beach during fall 2003.
- use the observations to test and improve numerical model predictions of cross-shore and alongshore fluid velocities.

APPROACH

Comparisons of field and laboratory observations with numerical model predictions and with theories for energy dissipation are being used to investigate swashzone processes, including the fluid velocities that are important to sediment transport. In particular, field observations of the cross-shore structure of cross-shore swashzone fluid velocities have been compared with Rbreak predictions (*Raubenheimer* 2002). Field and laboratory observations are being used to investigate swashzone turbulence and the vertical structure of the wave-induced cross-shore flows (*Cowen et al.* 2003, *Raubenheimer et al.* 2003). Additional field observations of swashzone flows to be collected in fall 2003 will be compared with an extension of Rbreak for non-normally incident waves to investigate the processes important to alongshore swashzone currents.

WORK COMPLETED

Surf- and swashzone waves and velocities were measured for 2 weeks during Fall 2000 along a cross-shore transect extending from about 3-m water depth to the shoreline (Figure 1).

Downward-looking acoustic doppler velocimeters (ADV) were deployed at 5 cross-shore locations and provided measurements at elevations above the bed z between 5 and 20 cm. Two sets of three horizontal-looking, vertically-stacked ADV probes (Figure 2) were deployed at z = 2, 5, and 8 cm. During low tides, the swashzone sensors were adjusted vertically to maintain approximately constant elevations above the bed. However, owing to sand level changes during tidal cycles, elevations above the bed of the lowest sensor z_l ranged from about 0.5 to 9.0 cm. Pressure sensors, buried just below sand level to measure wave and runup heights, were colocated with the velocimeters.

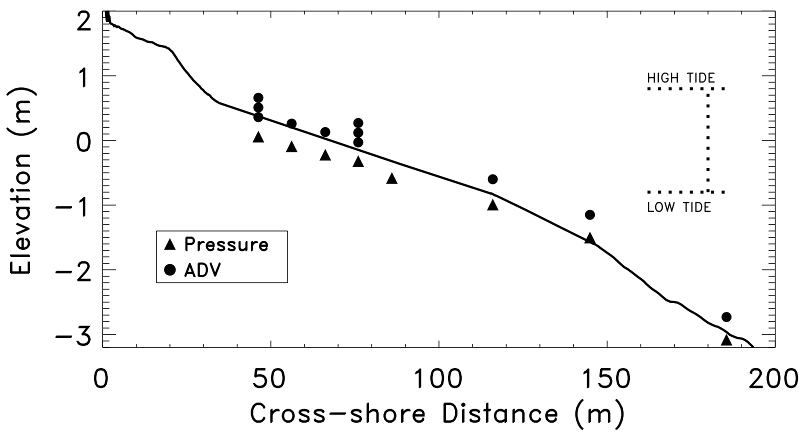

Figure 1. Scripps Beach profile (solid curve, slope ≈ 0.02) measured on Sep 28, 2000, and locations of acoustic doppler velocimeters (ADV, solid circles) and pressure sensors (solid triangles). Sensors were deployed in mean water depths -31.5, -14.5, -9.4, 6.1, 24.0, 82.9, 132.3, and 284.0 cm (negative values are above mean sea level).

Particle Image Velocimetry (PIV) and Laser Doppler Velocimetry (LDV) measurements of swashzone fluid velocities are being collected in a 32 m long, 0.6 m wide, 0.9 m deep wave tank in the DeFrees Hydraulic Laboratory at Cornell University. Measurements have been collected at five locations spanning the surf and swash zones for plunging and spilling type waves on a smooth glass beach. Cross-shore and vertical velocities were observed at 15 Hz for 332 s and ensemble-averaged resolving 30 wave phases. The spatially and temporally resolved velocity fields measured in plunging and spilling wave-driven swash zones are being used to investigate the boundary layer structure of the mean and turbulent quantities as well as the phase evolution of the bed shear stress, near-bed turbulent kinetic energy, and dissipation.

Sensors that will be used to measure alongshore swashzone flows have been tested and calibrated. Sensor frames and mounts have been designed and constructed. Data acquisition computers and radio transmitters (to send the data from the isolated shore stations on the beach to Scripps Institution of Oceanography [SIO]) have been built and tested. Bathymetric surveys are being conducted to determine the surf and swashzone sand levels from the SIO pier to Torrey Pines Beach, and will be used in conjunction with model simulations to determine deployment locations.

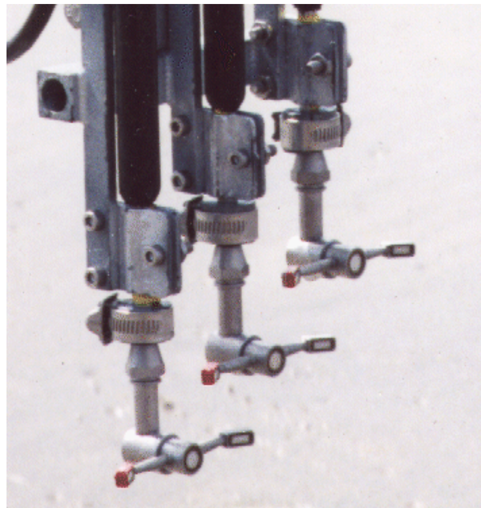

Figure 2. Stack of 3 acoustic Doppler velocimeters separated by 3 cm in the vertical and by 5 cm in the horizontal (cross-shore) direction. Velocimeter stacks were deployed in -31.5 and 6.1 mean water depths.

RESULTS

Field observations of the cross-shore structure of significant wave heights, root-mean-square orbital velocities, and mean offshore-directed flows in the surf and swash zones are predicted well by Rbreak (*Raubenheimer* 2002). However, the field and laboratory observations suggest that the cross-shore velocities are not uniform in the vertical, as assumed in the depth-averaged nonlinear shallow water equations. Observed velocity time series at the lowest sensor (Figure 3a) were roughly consistent with a logarithmic profile during both the uprush and downrush (*Raubenheimer et al.* 2003). The ratios of root-mean-square swashzone velocity fluctuations (i.e., velocity attenuation) measured at the lower u_l and upper u_h sensors (black circles in Figure 3b) and at the middle u_m and upper sensors (red triangles in Figure 3b), and the increase of attenuation with decreasing elevation of the lowest sensor z_l, were predicted qualitatively for 493 8.5-min sections of data. Note that for the data presented here and in *Raubenheimer* (2002) with $0.5 \leq z_l \leq 5.0$ cm, 80% of the observed rms ratios u_l/u_h were greater than 0.8, and thus the good agreement with Rbreak is not surprising.

The associated friction coefficients are similar in both the uprush and downrush, as in previous laboratory results. Turbulent dissipation rates estimated from velocity spectra increase with decreasing water depth from $O(400\ \text{cm}^2/\text{s}^3)$ in the inner surf zone to $O(1000\ \text{cm}^2/\text{s}^3)$ in the swash zone. Friction coefficients in the swash interior estimated with the logarithmic model, and independently estimated by assuming that turbulent dissipation is balanced by production from vertical shear of the local mean flow and from wave breaking, are between 0.02 and 0.06.

Preliminary measurements suggest that alongshore currents may reach a local maximum in the outer swash zone (Figure 4). The observations to be collected during fall 2003 will be used to determine whether this local maximum in the alongshore flow occurs for a wide range of conditions. The observations also will be used to test a time-domain model for alongshore swashzone currents owing to obliquely-incident waves and alongshore gradients in mean water level (e.g., wave setup).

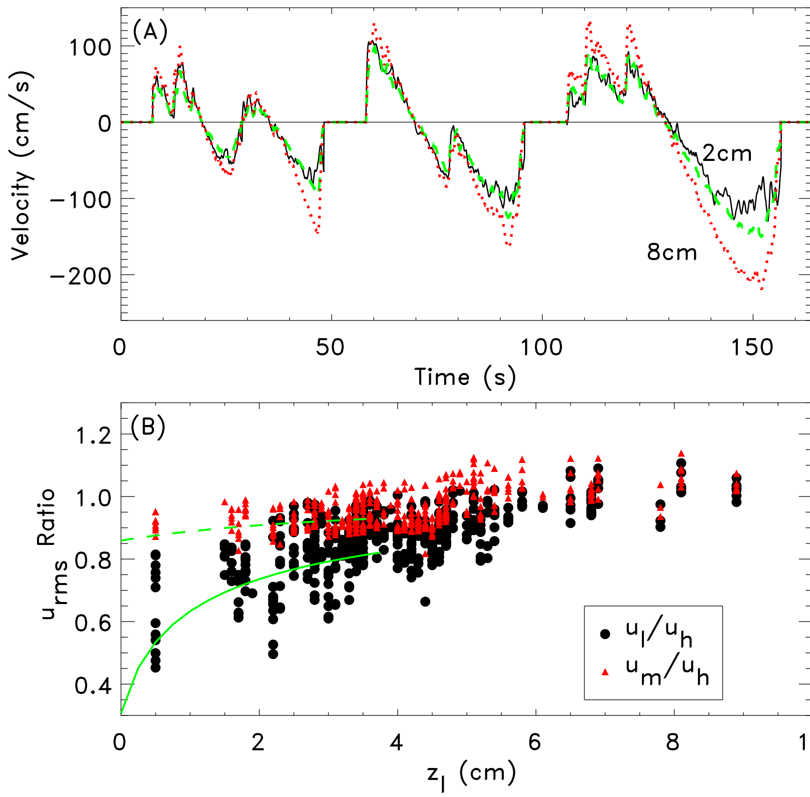

Figure 3. (A) Observed bandpass (0.004 $\leq f \leq 2.0$ Hz) cross-shore velocities on Oct 11 at 2 (solid black curve) and 8 cm (dotted red curve) above the bed, and velocities predicted 2 cm above the bed (dashed green curve) assuming a logarithmic vertical structure. [For three swashes occurring over 165 s the observed and predicted velocities at 2 cm above the bed agree well.] (B) Observed (symbols) and predicted (green curves) ratios of root-mean-square orbital swash velocities (u_{rms} ratios) at the lower and upper sensors (black circles and green solid curve, u_l/u_h), and at the middle and upper sensors (red triangles and green dashed curve, u_m/u_h). [The ratio u_h/u_l decreases roughly from 1.0 to 0.4 as z_l decreases from 9.0 to 0.5 cm, consistent with logarithmic-model predictions.]

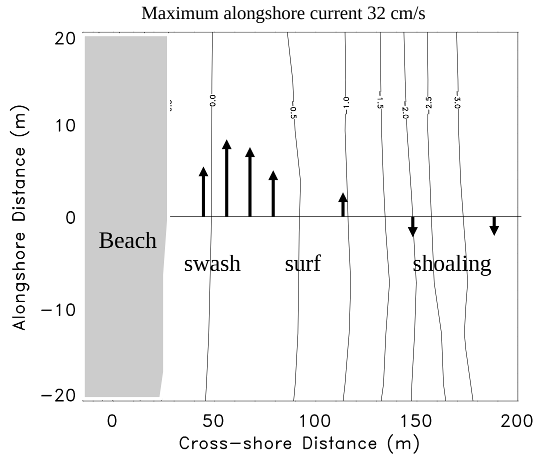

Figure 4. Observed 51-min-averaged alongshore swash flows (arrows) in the shoaling, surf, and swash regions. Thin black curves represent the measured sand level with respect to mean sea level. The observations were collected near mid-tide, and the dry area of the beach is shown by the grey region. [Alongshore flows are small and northward-directed in 2.0 to 3.0 m water depth, and are larger and southward-directed between 0.0 to 1.0 m water depth. The maximum alongshore flow occurs in about 0.2 m water depth.]

IMPACT/APPLICATIONS

Validated models of wave runup velocities may provide spatially dense predictions of cross-shore and alongshore swashzone flows to drive sediment transport models and to estimate morphological change. It is expected that the observations and field-tested models discussed here also will be useful to extend surfzone models into the swash zone. Evaluations of boundary layer parameterizations may provide a basis for revising time-domain models that assume quadratic bottom stresses.

RELATED PROJECTS

Observations from the in situ sensors in SwashX have been used to evaluate estimates of swash and surf zone velocities using drifters (Schmidt et al. 2003). The observations also are being used by postdoctoral researcher Tim Maddux to drive and evaluate models for swashzone sediment transport (Maddux et al. 2002).

The laboratory observations of swashzone fluid velocities are being conducted and analyzed in collaboration with E.A. Cowen and P.L.-F. Liu (Cornell Univ.). These studies are funded jointly by ONR and NSF.

The NSF Career program has provided funds for an undergraduate summer student fellow to participate in the swash study in fall 2003, and for fellows to investigate swash processes observed during SwashX and future experiments.

REFERENCES

Bodge, K.R., and R.G. Dean, Short-term impoundment of longshore transport, *Proc. Coastal Sed. '87*, 468-483, 1987.

Cowen, E.A., I.M. Sou, P.L.-F. Liu, and B. Raubenheimer, PIV measurements within a laboratory generated swash zone, *J. Eng. Mech., in press,* 2003.

Kamphuis, J.W., Alongshore sediment transport rate, *J. Waterw. Port Coastal Ocean Eng., 117,* 624-640, 1991.

Kobayashi, N., G. S. DeSilva, and K. D. Watson, Wave transformation and swash oscillation on gentle and steep slopes, *J. Geophys. Res., 94,* 951-966, 1989.

Raubenheimer, B., Observations and predictions of fluid velocities in the surf and swash zones, *J. Geophys. Res., 107,* 3190, doi:10.1029/2001JC001264, 2002.

Raubenheimer, B., R.T. Guza, S. Elgar, and N. Kobayashi, Swash on a gently sloping beach, *J. Geophys. Res., 100,* 8751-8760, 1995.

Raubenheimer, B., Steve Elgar, and R.T. Guza, Swashzone velocities, turbulent dissipation, and friction coefficients, *J. Geophys. Res., in review,* 2003.

Thornton, E.B., and S. Abdelrahman, Sediment transport in the swash due to obliquely incident wind waves modulated by infragravity waves, *Proc. Coastal Sed. '91,* 100-113, 1991.

PUBLICATIONS

REFEREED PAPERS:

Raubenheimer, B., Observations and predictions of fluid velocities in the surf and swash zones, J. Geophys. Res., 107, 3190, doi:10.1029/2001JC001264, 2002 [published, refereed].

Schmidt, W.E., B.T. Woodward, K.S. Millikan, R.T. Guza, B. Raubenheimer, and S. Elgar, A GPS-tracked surfzone drifter, J. Atmos. Ocean Tech., 20(7), 1069-1075, 2003 [published, refereed].

Elgar, Steve, B. Raubenheimer, and T.H.C. Herbers, Bragg reflection of ocean waves from sandbars, Geophys. Res. Lett., 30(1), doi:10.1029/2002GL016351, 2003 [published, refereed].

Cowen, E.A., I.M. Sou, P.L.-F. Liu, and B. Raubenheimer, PIV measurements within a laboratory generated swash zone, J. Eng. Mech., 2003 [in press, refereed].

Raubenheimer, B., Steve Elgar, and R.T. Guza, Swashzone velocities, turbulent dissipation, and friction coefficients, J. Geophys. Res., 2003, [submitted, refereed].

CONFERENCE ABSTRACTS:

Elgar, S., B. Raubenheimer, and T.H.C. Herbers, Bragg reflection of ocean waves from sandbars, EOS Trans., 83, 2002.

Maddux, T.B., B. Raubenheimer, S. Elgar, Predictions of cross-shore sediment transport in the inner surf and swash zones, EOS Trans., 83, 2002.

HONORS/AWARDS/PRIZES

Britt Raubenheimer, Woods Hole Oceanographic Institution, Young Investigator Award, ONR, 2000.

Britt Raubenheimer, Woods Hole Oceanographic Institution, Career Award, NSF, 2003.